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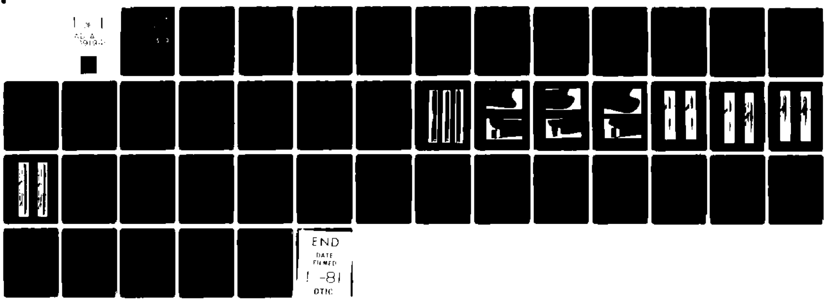

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

LEVEL II

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CORRELATION OF MODEL EXPERIMENTS WITH SHIP POWERING DATA FOR THREE TANKERS REPRESENTED BY MODELS 9006, 9007, 9008, AND 9009

by

W. G. DAY

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SHIP PERFORMANCE DEPARTMENT REPORT

OCTOBER 1980

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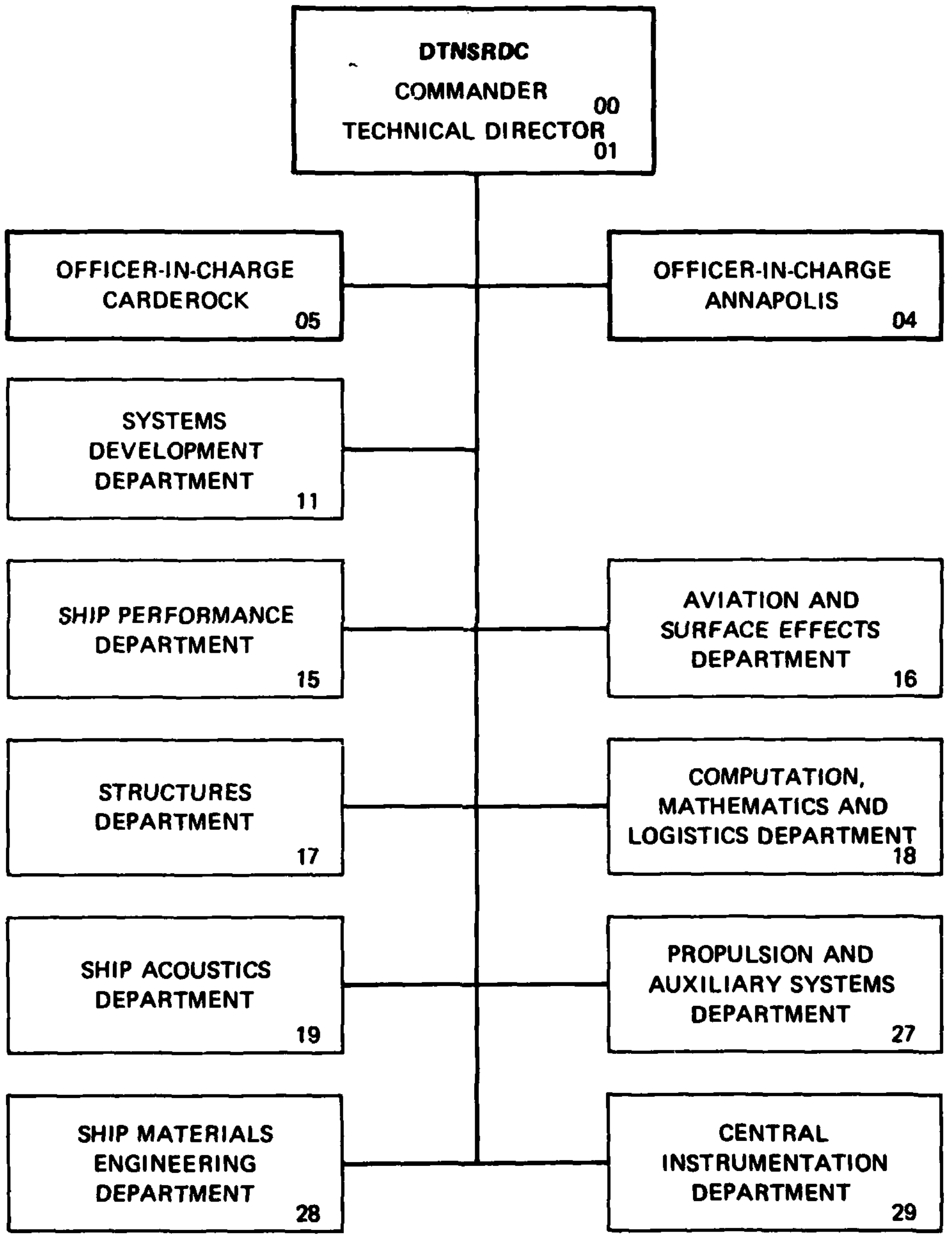

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) DTNSRDC/SPD-0851-01	2. GOVT ACCESSION NO. AD-A097 940	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) CORRELATION OF MODEL EXPERIMENTS WITH SHIP POWERING DATA FOR THREE TANKERS REPRESENTED BY MODELS 9006, 9007, 9008, AND 9009.		5. TYPE OF REPORT & PERIOD COVERED (9) final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) W. G. DAY		8. CONTRACT OR GRANT NUMBER(s) (12) 44
9. PERFORMING ORGANIZATION NAME AND ADDRESS DAVID W TAYLOR NAVAL SHIP R&D CENTER BETHESDA, MD. 20084 (11) Oct 80		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 4-1500-001-49
11. CONTROLLING OFFICE NAME AND ADDRESS DAVID W TAYLOR NAVAL SHIP R&D CENTER BETHESDA, MD 20084		12. REPORT DATE OCTOBER 1980
		13. NUMBER OF PAGES 35
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) U. S. DEPARTMENT OF COMMERCE MARITIME ADMINISTRATION WASHINGTON D. C. 20362		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CORRELATION ALLOWANCE
TANKERS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Powering data from trials of three tankers have been correlated with predictions from experiments with four models, (one of the tankers being represented by two models of varying size). The correlation allowance ranged from -0.00015 to -0.0004. This range of correlation allowance is lower than anticipated, but is in agreement with an apparent trend of negative correlation allowances for modern tankers over 300 meters in length.

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S/N 0102-LF-014-6601

Unclassified

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NOTATION

C_A	Correlation allowance
C_F	Frictional resistance coefficient, $R_F/\frac{1}{2}\rho V^2 S$
C_R	Residuary resistance coefficient, $R_R/\frac{1}{2}\rho V^2 S$
C_T	Total resistance coefficient, $R_T/\frac{1}{2}\rho V^2 S$
D	Propeller diameter
g	Acceleration due to gravity
J	Advance coefficient of propeller, V_A/nD
J_T	Advance coefficient based on thrust identity
J_V	Advance coefficient based on ship speed
K_Q (KQ)*	Torque coefficient of propeller, $Q/\rho n^2 D^5$
K_T (KT)	Thrust coefficient of propeller, $T/\rho n^2 D^4$
L	Length
n	Propeller rate of revolution
P_D	Delivered power
P_E	Effective power
Q	Torque
R_n	Reynolds number
R_F	Frictional resistance
R_R	Residuary Resistance ($R_R = R_T - R_F$)
R_T	Total resistance

*Symbols in parentheses are computer-compatable notation used in computer generated tables.

NOTATION (continued)

S		Wetted surface area
T		Thrust
t		Thrust deduction fraction
V		Speed
V_A		Speed of advance of propeller
w_Q	(WQ)*	Taylor wake fraction determined from torque identity
w_T	(WT)	Taylor wake fraction determined from thrust identity
η_D	(ETAD)	Propulsive efficiency
η_H	(ETAH)	Hull efficiency $(1-t)/(1-w_T)$
η_O	(ETAO)	Propeller efficiency in open water $(T\ V_A/2\pi\ Qn)$
η_R	(ETAR)	Relative-rotative efficiency
λ		Scale ratio
ρ		Mass density
ν		Kinematic viscosity

Subscripts S and M refer to ship and model dimensions, respectively.

ENGLISH/SI EQUIVALENTS

ENGLISH	SI
1 inch	25.400 millimeters [0.0254 m (meters)]
1 foot	0.3048 m (meters)
1 foot per second	0.3048 m/sec (meters per second)
1 knot	0.5144 m/sec (meters per second)
1 pound (force)	4.4480 N (Newtons)
1 degree (angle)	0.01745 rad (radians)
1 horsepower	0.7457 kW (kilowatts)
1 long ton	1.016 tonnes, 1.016 metric tons, or 1016 kilograms

ABSTRACT

Powering data from trials of three tankers have been correlated with predictions from experiments with four models, (one of the tankers being represented by two models of varying size). The correlation allowance ranged from -0.00015 to -0.0004. This range of correlation allowance is lower than anticipated, but is in agreement with an apparent trend of negative correlation allowances for modern tankers over 300 meters in length.

ADMINISTRATIVE INFORMATION

This project was initiated by Panel H-2 (Resistance and Propulsion) of the Society of Naval Architects and Marine Engineers. As part of a cooperative effort, the Ship Performance Department of the David W. Taylor Naval Ship R&D Center supported this work under work unit 4-1500-001-49.

INTRODUCTION

A ship-model correlation project for large full-form tanker hulls was proposed by Panel H-2 (Resistance and Propulsion) of the Society of Naval Architects and Marine Engineers (SNAME). Very few ship-model correlations have been performed by U.S. towing tanks on ships of this type since most of the design-development work has been performed in European and Japanese model tanks. A survey done by Panel H-2 of ship owners, designers and builders indicated that such data would be of prime interest to the U.S. shipbuilding industry and would strengthen the capability of U.S. towing tanks.

The correlation project was performed cooperatively by ship owners, the Maritime Administration and the three towing tanks initially involved. Construction of hull and propeller models and overall project administration were funded by the Maritime Administration. Experiments were funded and conducted by the David W. Taylor Naval Ship R&D Center (DTNSRDC), the University of Michigan, and Hydronautics, Incorporated. Overall project administration,and construction of all models were provided by Hydronautics, Inc. The full scale trial data were provided by private oil companies from builders' trials which had been funded by these companies.

This report documents the correlation experiments performed at DTNSRDC.

A summary of the full-scale trial data is provided. Hull and propeller model geometries are listed for reference. The powering experimental data and the resulting correlation allowance values for each of the four ship models are presented herein. The values of correlation allowance were negative, ranging from -0.00015 to -0.0004, which is consistent with such data reported by other towing tanks for ships of this type.

FULL SCALE DATA

Powering data from standardization trials were provided by private companies with the understanding that the ships would not be identified. Therefore, only the DTNSRDC hull model number is used to identify the individual ships. Ship and propeller geometries were provided for model construction. A brief list of hull and propeller characteristics and ship standardization trial data are presented in Tables 1, 2, and 3.

Actual measurements of wind velocity and direction during the trials were not made available to the Center; therefore, the effects of wind drag on performance are not known precisely. The only correction which has been applied to the full-scale data is one for still-air drag. This correction has been applied to the trial speeds using the method described by Wilson and Roddy[1]. Correlation allowance values derived from full-scale trial data, which have been corrected for still-air drag, are as much as 0.00009 less than the correlation allowances which would be obtained from uncorrected full-scale data.

DESCRIPTION OF MODELS AND TOW TANK EXPERIMENTS

Four hull models were constructed of fiberglass by Hydronautics, Inc. for use in these correlation experiments. DTNSRDC model numbers 9006 through 9009 were assigned to these hull models for identification. Models 9006 and 9009 are geosims of the same full-scale ship hull, but, are built to different scale ratios. Dimensions of each model hull and propeller are presented in Table 4. The model scale ratios were chosen to produce model propeller diameters as close to 203 mm as possible. However, a model hull size no greater than approximately 7.0 meters was desired in order to avoid a large blockage problem in the smaller tanks.

[1]References are listed on page 6.

Model 9009 was built to a scale ratio that would result in a model that could be towed in the deep-water basin at DTNSRDC without significant blockage effects on resistance. This model was also towed in the Hydronautics Ship Model Basin and blockage correctors in use at that facility were applied to the data.

Fitting-room photographs of Models 9006, 9007 and 9008 are presented in Figures 1 through 4; no photographs of Model 9009, which is a geosim of Model 9006, are included.

Two rows of cylindrical studs and a trip wire were used to stimulate turbulence on all four models. The forward row of studs was placed on the bulbous bow approximately midway between the bulb ending and the forward waterline ending. The after row of studs was placed on the girth section at approximately L/20 aft of the forward waterline ending. The trip wire was placed aft of the second row of studs in the area of the beginning of the parallel midbody, in order to prevent separation at this point. The studs and tripwire on Models 9006 through 9008 can be seen in Figures 2 through 4.

Wave profile photographs of the models appear in Figures 5 through 8. The only photograph of Model 9007 underway was taken at a speed corresponding to 12 knots rather than 16.5 knots, which was the speed at which photographs were taken of the other three models. A photograph of each model at rest is presented for reference. The similarity in wave profiles for the geometrically-similar hulls may be noted by comparing Figures 5 and 8.

Four propeller models were constructed of aluminum by Hydronautics to be used in these experiments. DTNSRDC propeller numbers 9008 through 9011 were assigned to these propellers for identification. The propellers were characterized in open water at DTNSRDC and the results of the experiments are presented in Figures 9 through 12.

The correlation experiments reported herein were conducted in the DTNSRDC Deep-Water Towing Basin using Carriage 1. No blockage correction was applied to any of the data, since the normal blockage calculations indicated a negligible effect. Resistance and propulsion experiments were performed utilizing the standard instrumentation and data reduction techniques currently used at DTNSRDC.[2] Resistance data were extrapolated to trial conditions through employment of the 1957 ITTC Ship-Model Correlation Line.

Propulsion experiments were run at the ship propulsion point for three correlation allowances: +0.0002, 0, and -0.0002. The results from the ship trial data were cross-fiared and used to determine the final values of correlation allowance. For those cases where the correlation allowance was outside the range used in the model propulsion experiments, a linear extrapolation of the model data determined final correlaticn allowance values. Faired-power predictions for the ships represented by Models 9006 through 9009 are presented in Figures 13 through 16. The full-scale delivered power values which were provided by the ship owners are also shown on the figures. Predicted powering performance and propeller-hull interaction coefficients are presented for each hull in Tables 5 through 8. Table 9 presents a comparison of predictions from model experiments, with full-scale power and propeller revolution measurements for each ship.

DISCUSSION

The results of these correlation experiments indicate that the required correlation allowance is between -0.00015 and -0.0004 for large, full-form tankers. These values are consistent with other model extrapolations for ships of this type as reported in ITTC publications. Negative values of correlation allowance have not been derived in previous ship-model correlation experiments at DTNSRDC. However, very few experiments with models of large full-form tankers have been run at the Center.

To ascertain whether the large negative values of correlation allowance could be explained by a "form factor" influence on the frictional resistance, another technique was used to extrapolate the resistance data from model scale to full scale. The form-factor method proposed by Hughes[3] was used to determine the frictional and residuary resistance coefficients. The Hughes form-factor method assumes that the total resistance coefficient of the ship or model at very low Froude numbers is a sum of the flat-plate frictional resistance coefficient and a constant factor times that frictional resistance coefficient. The method for obtaining the constant factor requires that the total resistance coefficient of the model be determined for a range of very low Froude numbers at which the total resistance coefficient is a constant factor of the frictional resistance coefficient.

Unfortunately, the magnitude of the model resistance was so small at the low Froude numbers that measurement inaccuracies resulted in large scatter of the total resistance coefficient. Therefore, no constant form factor could be determined from these data.

In order to reduce the scatter in the total resistance coefficient of the models the raw drag measurements were faired with a least-squares fit. The curve-fit values of model resistance were used in calculations of total resistance coefficient. Although a smooth curve of total resistance coefficient resulted from this procedure, the values were not a constant percentage higher than the frictional resistance coefficient for the low Froude numbers. Therefore, no constant form factor could be determined by this approach.

In addition to the attempts to use the Hughes method to determine a form factor, the procedure outlined by Prohaska[4] in the Eleventh International Towing Tank Conference was tried. Prohaska proposed that the Froude number to the fourth power divided by the frictional resistance coefficient be used as a speed parameter in order to give a linear variation of the ratio of total resistance coefficient to frictional resistance coefficient. The zero-Froude-number intercept determined the form factor. Results of this procedure applied to the two geosim models, Models 9006 and 9009, produced a straight-line variation (allowing for a great deal of scatter) and an intercept which was similar for both models. The form factor obtained was 0.31 which is not inconsistent with other data of this type reported by Prohaska[4] and Granville[5]. One would conclude that Prohaska's procedure for determining form factor is successful in these cases. This form factor used with the ITTC Ship-Model correlation line changed the correlation allowance from -0.00015 to +0.0003. This change in correlation allowance is consistent with data reported by Tamura[6].

The difference in correlation allowance comes primarily from the different amount of viscous pressure drag attributed to the full-scale ship. The total full-scale viscous pressure drag estimated in accordance with the Hughes method is substantially lower than that estimated by traditional Froude methods using a flat plate extrapolator. It should be

noted, however, that only if the correlation allowance values show more consistency can a particular technique be considered preferable. If the form factor technique gives only positive values of correlation allowance, without reducing the variability, then one is still at the mercy of a random estimate of C_A for future performance predictions. In any event, only by performing many trial correlations can such consistency be determined.

In future work with experiments using models of large, full-form ships, different instrumentation is recommended in order to obtain a better set of data with which to determine form factors. Furthermore, Prohaska's procedure for fairing the resistance data will be used to obtain a form factor for extrapolating model resistance data to full-scale predictions.

The difference between the propeller revolutions per minute (RPM) predicted from experiments with Models 9007 and 9008 and those measured on full-scale trials is larger than normally expected for surface ship hulls. In these cases the propeller RPM measured on full-scale trials is higher than the propeller RPM predicted from model experiments by about 3 percent for Model 9007 and by about 6 percent for Model 9008. The fact that the propeller RPM is higher at full scale than that predicted from model experiments could be attributed to the differences in inflow velocity to the propeller and to differences in propeller blade drag coefficient between the ship and model propeller Reynolds numbers. The relative increase in propeller inflow velocity at the full scale results from the relatively thinner turbulent boundary layer on a smooth hull at full-scale Reynolds numbers. The propeller blade section drag coefficient is also lower at full-scale Reynolds numbers than at model-scale Reynolds numbers. The changes in wake fraction and blade section drag both produce a reduction in propeller torque, which is counteracted by an increase in propeller RPM in order to develop a specified power.

Traditional extrapolation procedures in use at DTNSRDC do not account for the wake difference between a full-scale ship and its geosim model. Similarly propeller thrust and torque characteristics are considered the same at both scales in the traditional extrapolation. However, new procedures developed at DTNSRDC, based on axisymmetric body boundary layer calculations

and propeller performance (inverse) calculations, have attempted to account for such Reynolds numbers effects and have succeeded in making more accurate predictions of the full-scale propeller RPM. The technique has not been verified for surface ship hulls. Nevertheless, it is expected that the procedure would result in a higher predicted propeller RPM for the same shaft power. It is recommended that future efforts with large full-form tankers use this technique in addition to the more traditional methods in extrapolating model experimental data to full-scale propeller RPM predictions.

Finally, it should be noted that the two geosim models agree reasonably well in predicting the highest trial power. Differences between the experiments with Model 9006 and 9009 are mostly within experimental accuracy. The propulsive efficiency (η_D) agrees within 0.015. The resistance predictions agree very well, with the residuary resistance coefficient was within 0.1×10^{-3} for both models. Similarly, the thrust deduction is in good agreement (0.76 vs 0.77) between the two models. The difference in propulsive efficiency is less than 2 percent in delivered power prediction at the highest trial speed, with Model 9006 predicting slightly less than the full-scale value and Model 9009 slightly higher. In either event, the predictions were in acceptable agreement with the full-scale result. In view of the slightly better agreement of the predicted propeller rpm from the large model with the full-scale measurement, it is recommended that future experiments be performed with the largest size model that can be accommodated by the deep water basin.

Although the form-factor approach to extrapolating model resistance values to full-scale performance predictions resulted in a positive correlation allowance, the prediction accuracy of full-scale performance was not necessarily improved over that of a traditional flat-plate extrapolation. For the three ships under consideration the spread in correlation allowance is of the same magnitude with either approach. Prohaska's technique for determining form factor appears to be capable of bypassing the low measurement-accuracy problem at the very low Froude number speed range. Both Prohaska's and Hughes' technique result in positive values of correlation allowance.

The results of these ship-model correlation experiments show that there may be some flow phenomena on the models which do not represent the full-scale ship flow. In particular, the results of the propeller rpm prediction show the need for a better account of the viscous flow pattern on the hulls of both models and full-scale ships. It is even possible that flow phenomenon such as separation may occur in the model-scale experiments and not in the full-scale trial. Neither traditional nor form-factor approaches account for such a flow situation. A three-dimensional approach is needed to define the viscous flow characteristics, such as boundary layer development or flow separation. Such a three-dimensional viscous flow calculation would enable the experimenter to develop a more rational technique of extrapolating the model data to full-scale performance predictions. In the meantime, the traditional or form factor approach may be used to predict full-scale performance.

CONCLUSIONS

The results of these ship-model correlation experiments show reasonable predictions of ship trial performance for shaft power. It is recommended that extrapolation of the results of future experiments with models of large full-form tankers be performed with a correlation allowance lower than the value of 0.0002 currently in use for commercial ships. A value of -0.0002 appears reasonable when using traditional extrapolation procedures based on these experiments. The form-factor approach to extrapolation, using Prohaska's technique to determine the form factor, resulted in positive values of correlation allowance. Based on the limited experience reported herein, however, this approval provides no better prediction of full-scale shaft power

The propeller revolutions per minute predicted by traditional methods from these model data are lower than those measured on full-scale trials. The prediction of propeller rpm should incorporate corrections for differences in hull boundary layer and propeller blade section drag between model and ship scales, in addition to the more traditional extrapolation procedures.

As an interim procedure, the traditional approach to extrapolating model experimental data to full scale performance predictions is recommended. In conjunction with this approach, correlation allowance values shown in Reference 6 appear to give reasonable predictions of full-scale shaft-power performance.

It is also recommended that future extrapolations of model data for full-form ships be performed with both traditional and form-factor methods, to observe which approach will provide more consistent values of correlation allowance. Whichever approach gives the smaller variation in correlation allowance would be the preferable technique for future extrapolations.

Finally it is recommended that a more rational method be developed for calculating three-dimensional viscous flows. Such a method would then be used in estimating viscous drag of model and ship as well as in estimating the full-scale propeller revolutions per minute.

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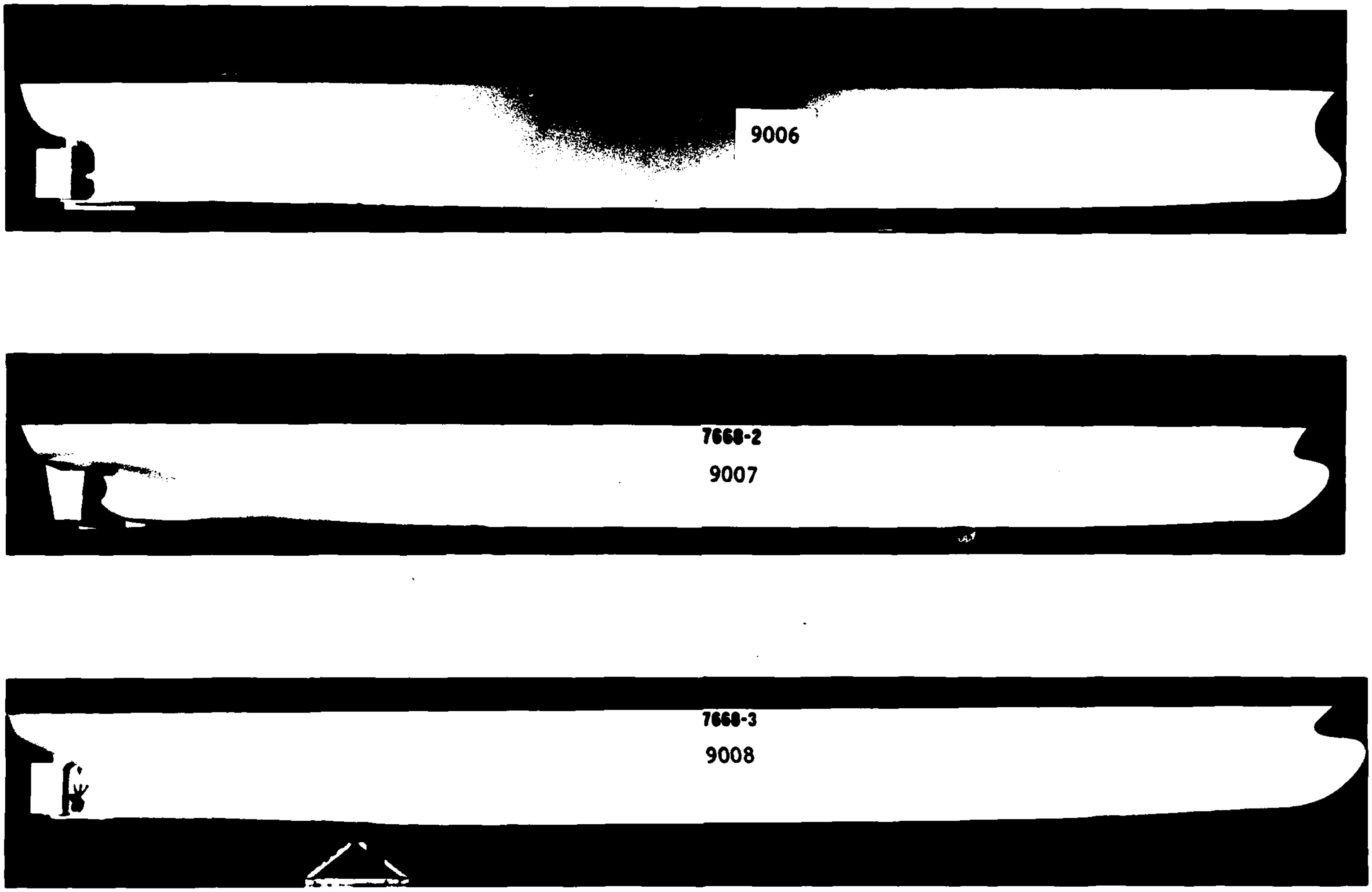


FIGURE 1 - Fitting Room Photographs of Profiles of Models 9006, 9007 and 9008

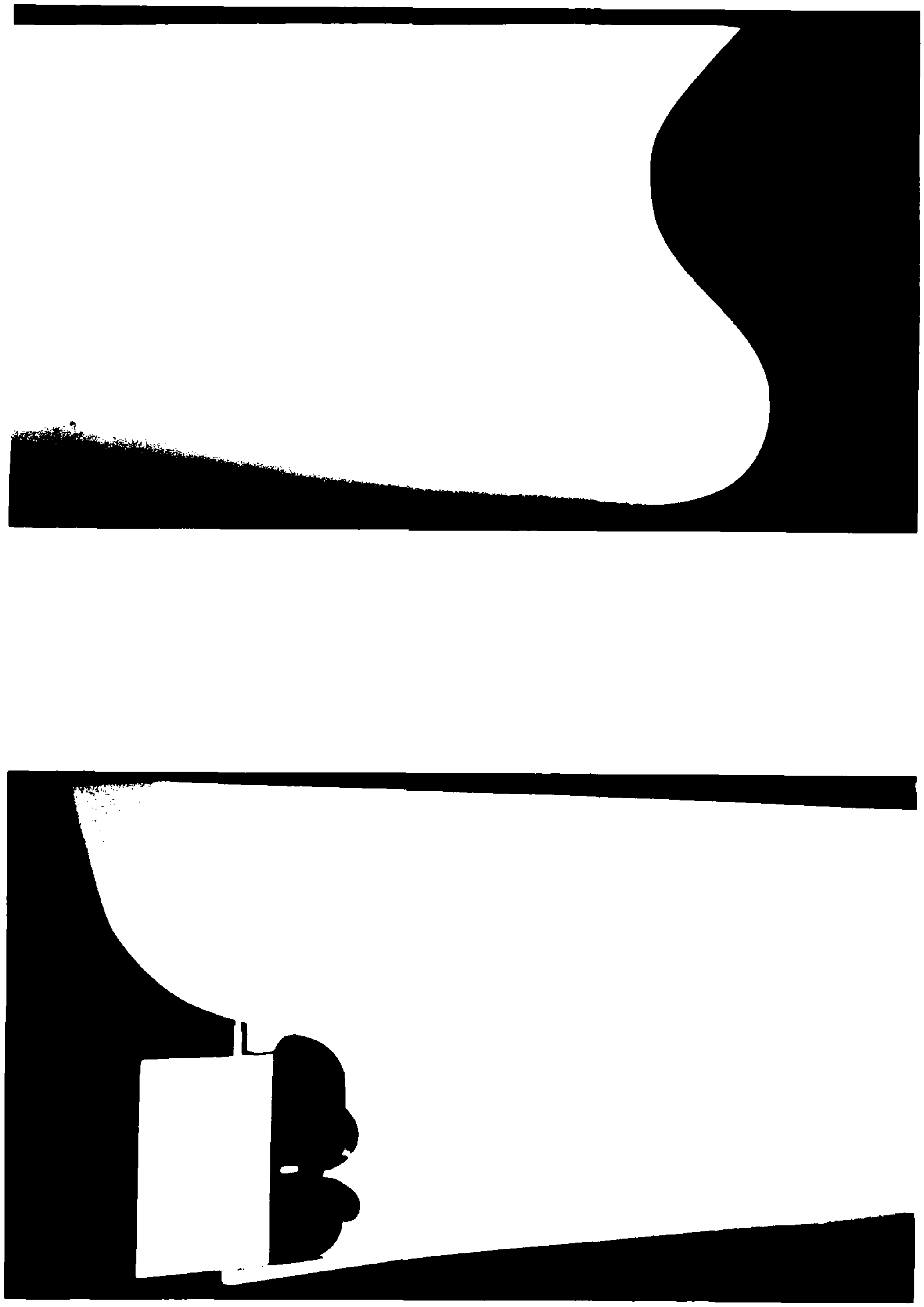


Figure 2 - Fitting Room Photographs of Bow and Stern Views of Model 9006

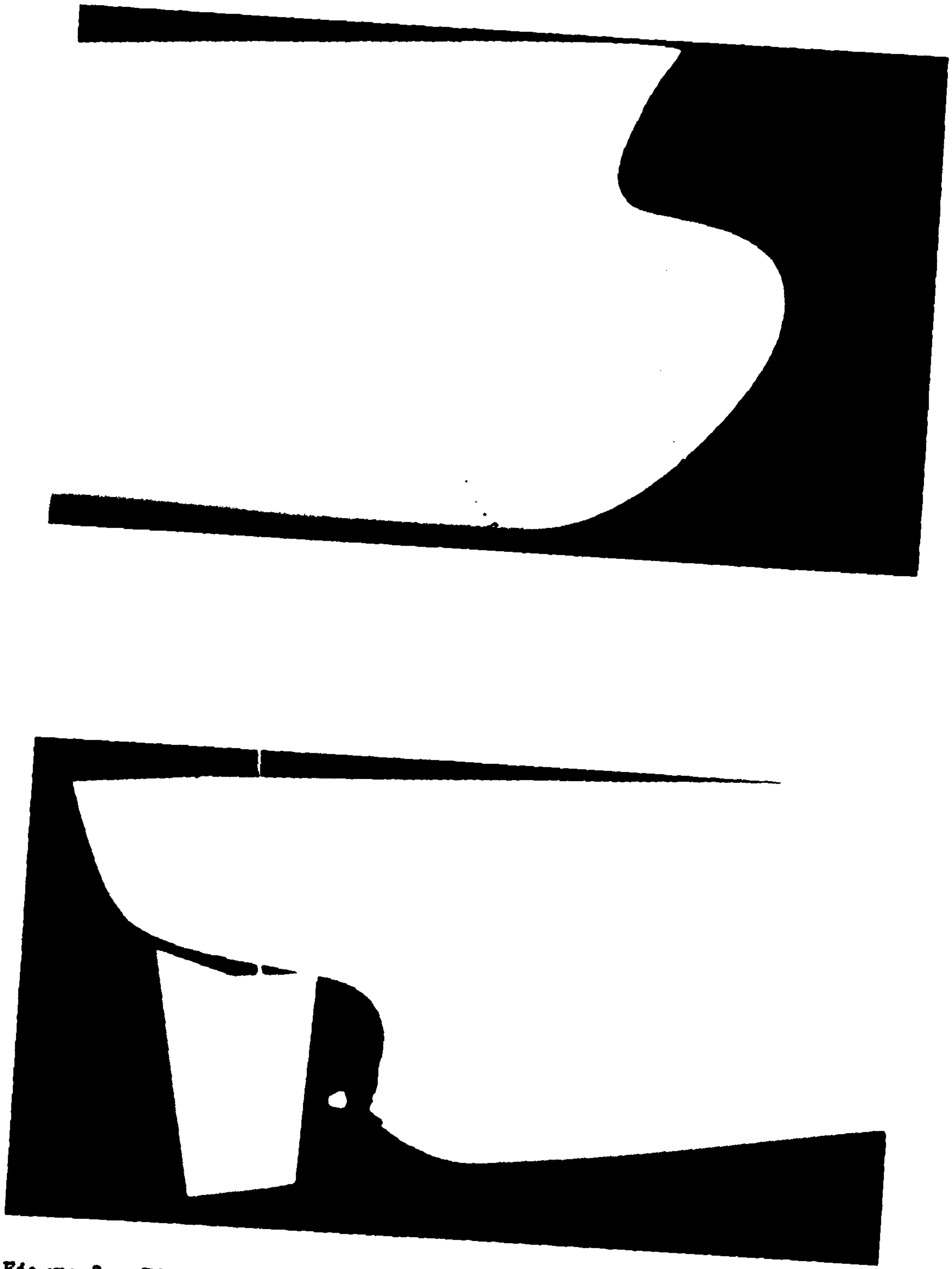
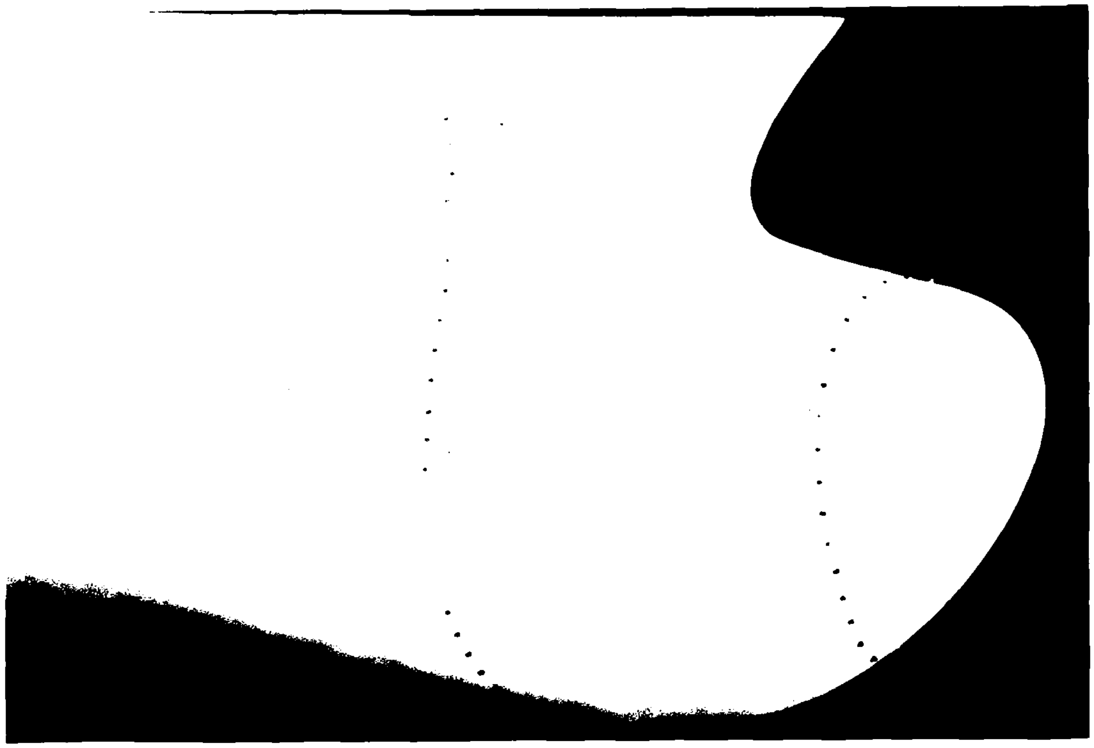


Figure 3 - Fitting Room Photographs of Bow and Stern Views of Model 9007



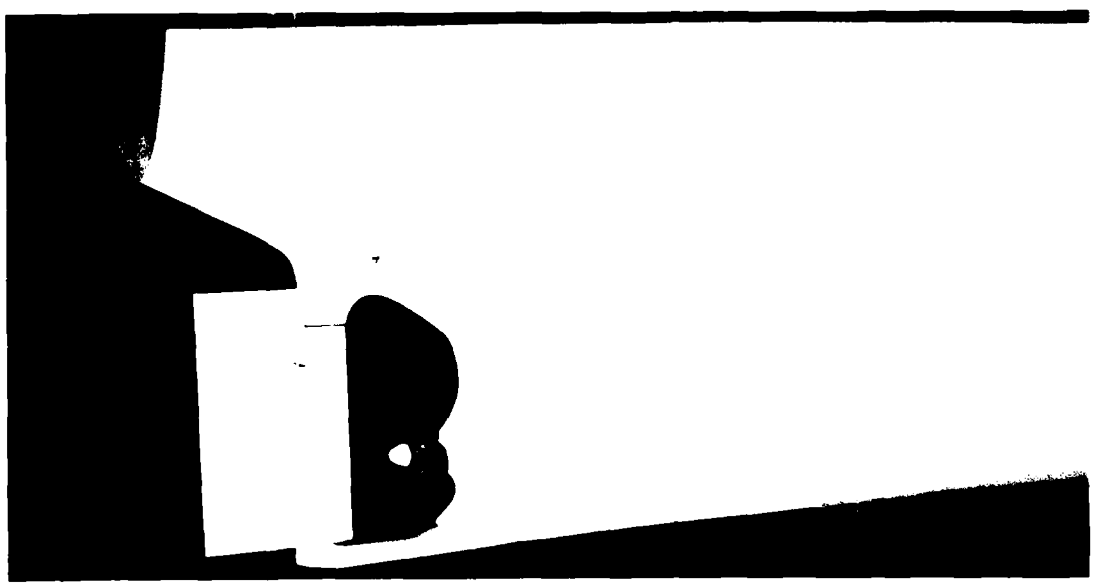


Figure 4 - Fitting Room Photographs of Bow and Stern Views of Model 9008

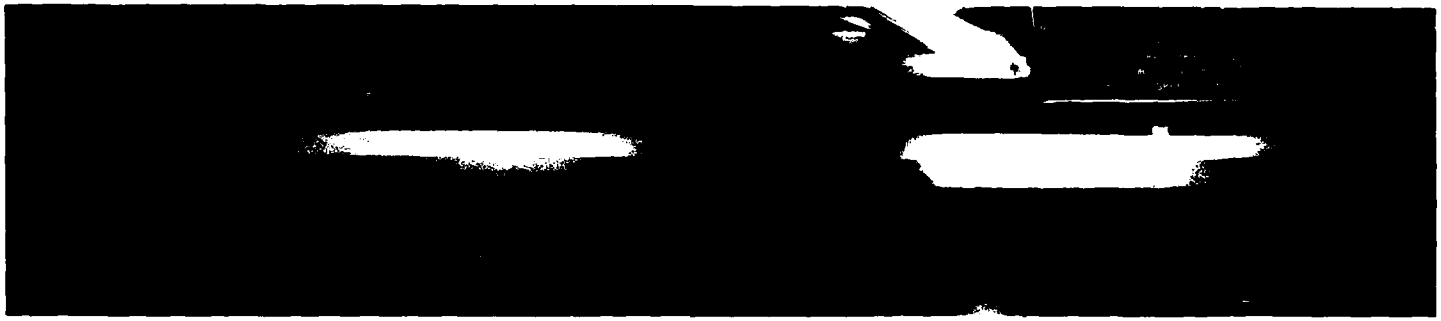


Figure 5A - Equivalent Ship Speed 0 Knots

Figure 5B - Equivalent Ship Speed 16.5 Knots

Figure 5 - Wave Profile Photographs of Model 9006

Figure 6A - Equivalent Ship Speed 0 Knots

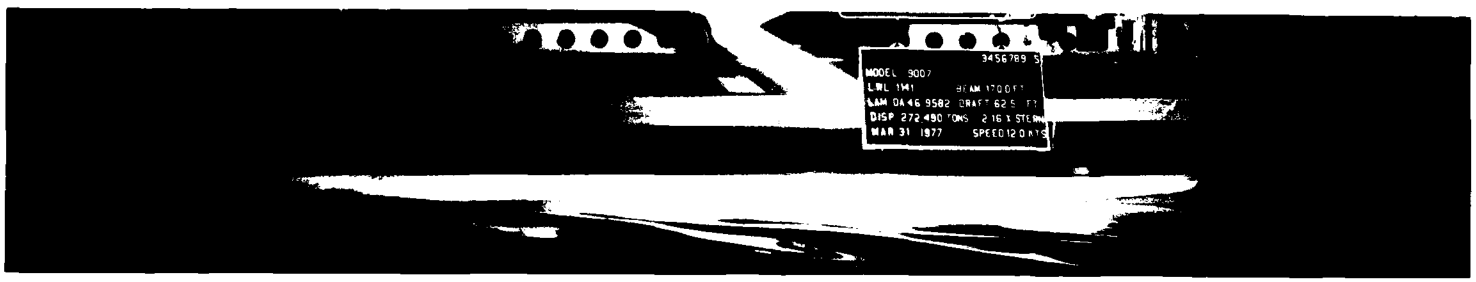


Figure 6B - Equivalent Ship Speed 12 Knots

Figure 6 - Wave Profile Photographs of Model 9007

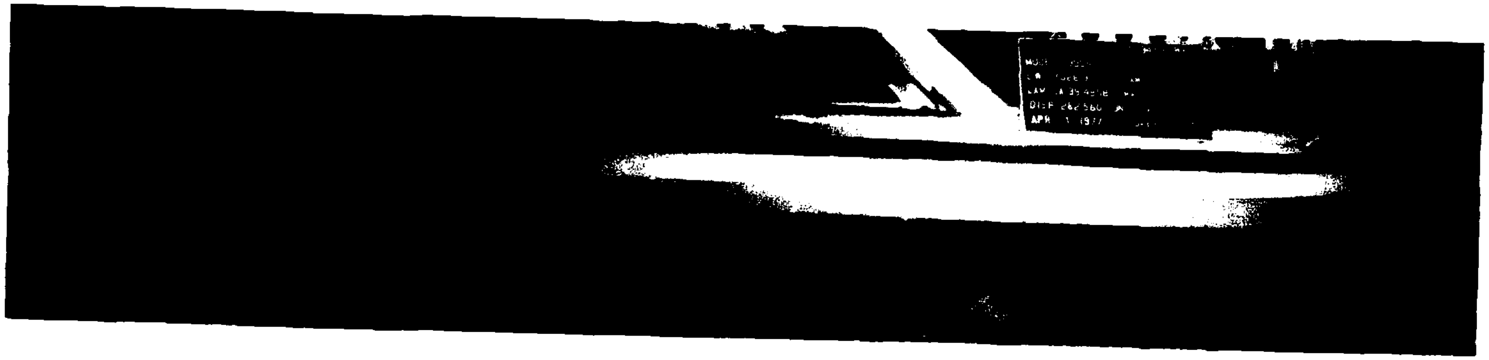


Figure 7A - Equivalent Ship Speed 0 Knots

Figure 7B - Equivalent Ship Speed 16.5 Knots

Figure 7 - Wave Profile Photographs of Model 9008

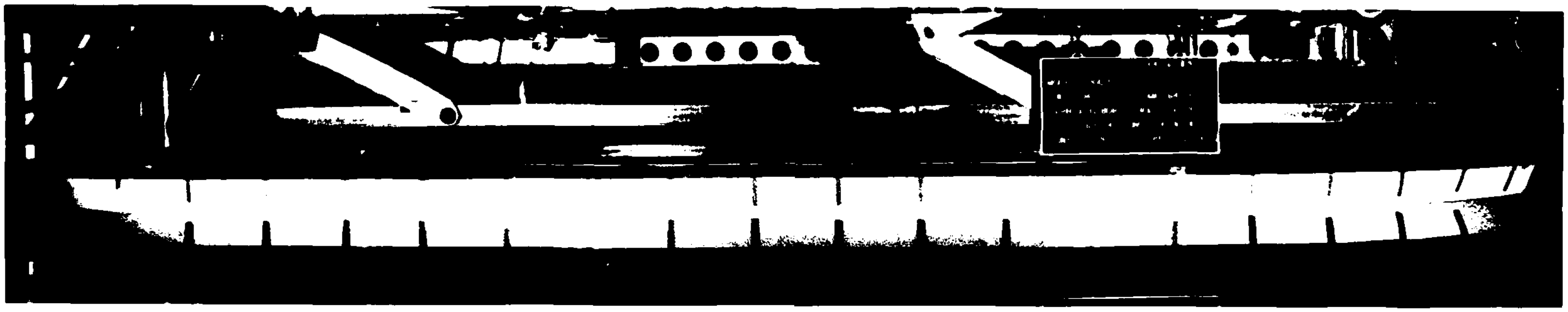


Figure 8A - Equivalent Ship Speed 0 Knots

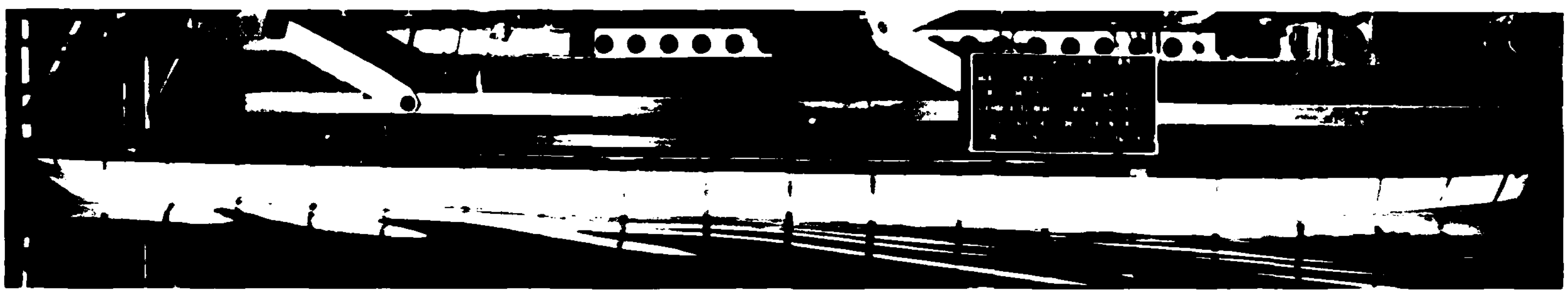


Figure 8B - Equivalent Ship Speed 16.5 Knots

Figure 8 - Wave Profile Photographs of Model 9009

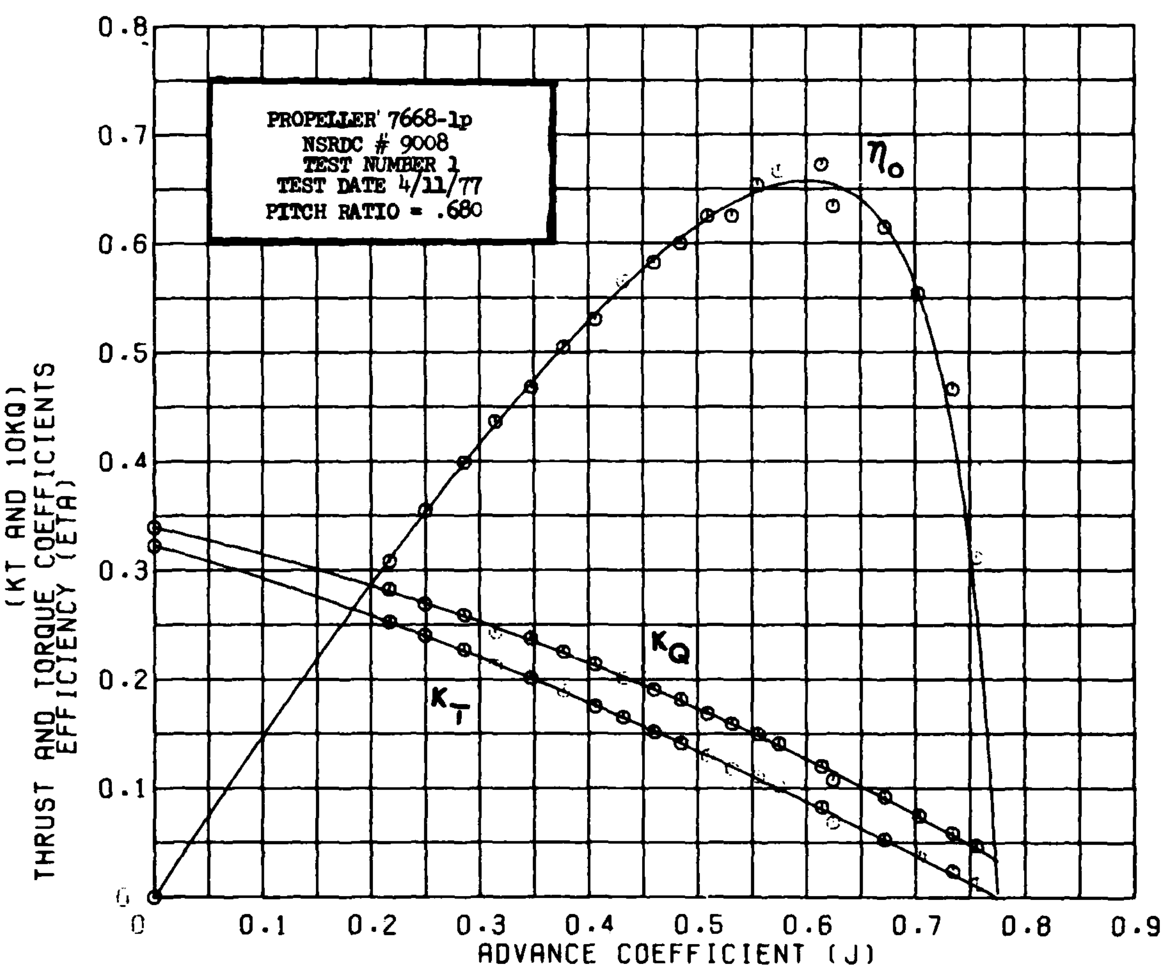


Figure 9 - Open Water Curves for Propeller 9008

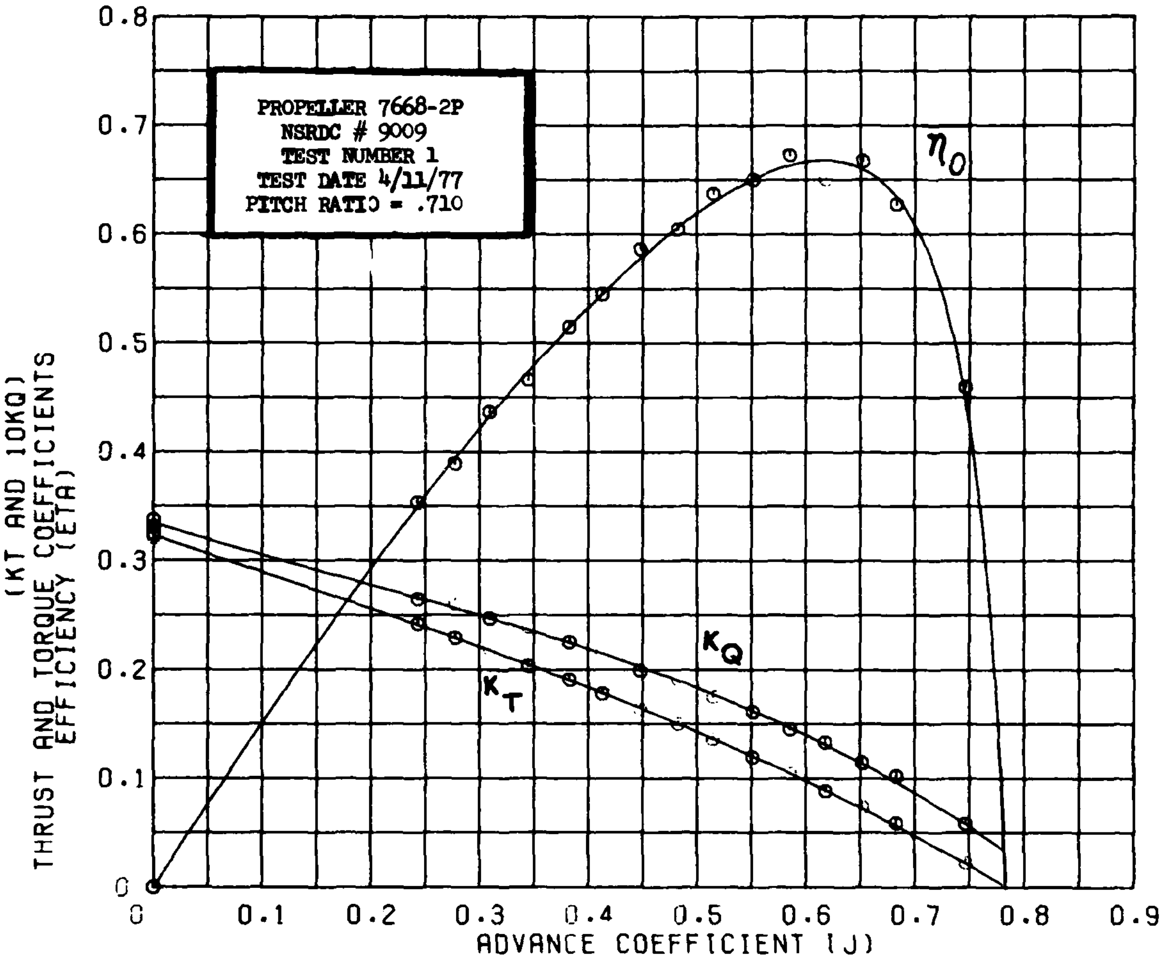


Figure 10 - Open Water Curves for Propeller 9009

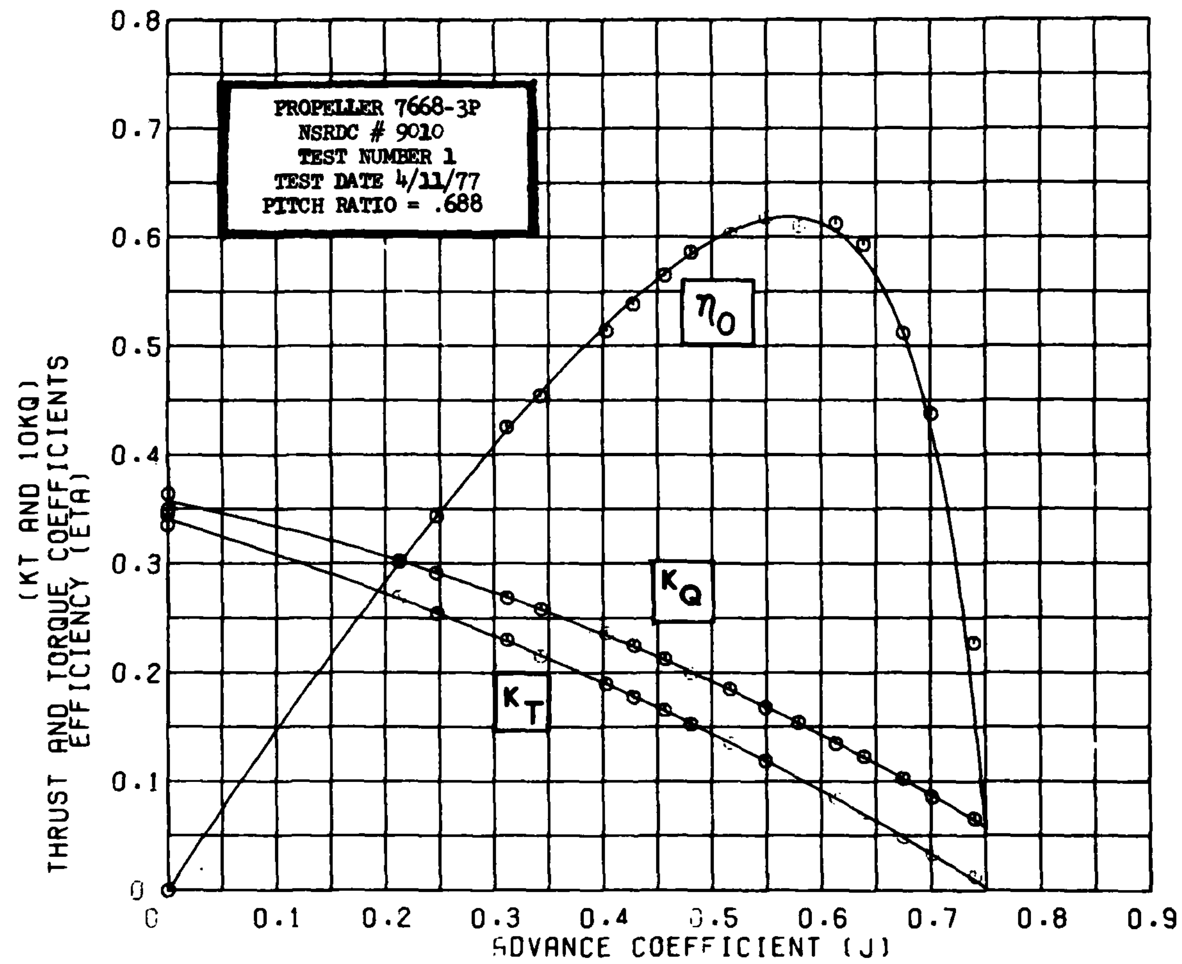


Figure 11 - Open Water Curves for Propeller 9010

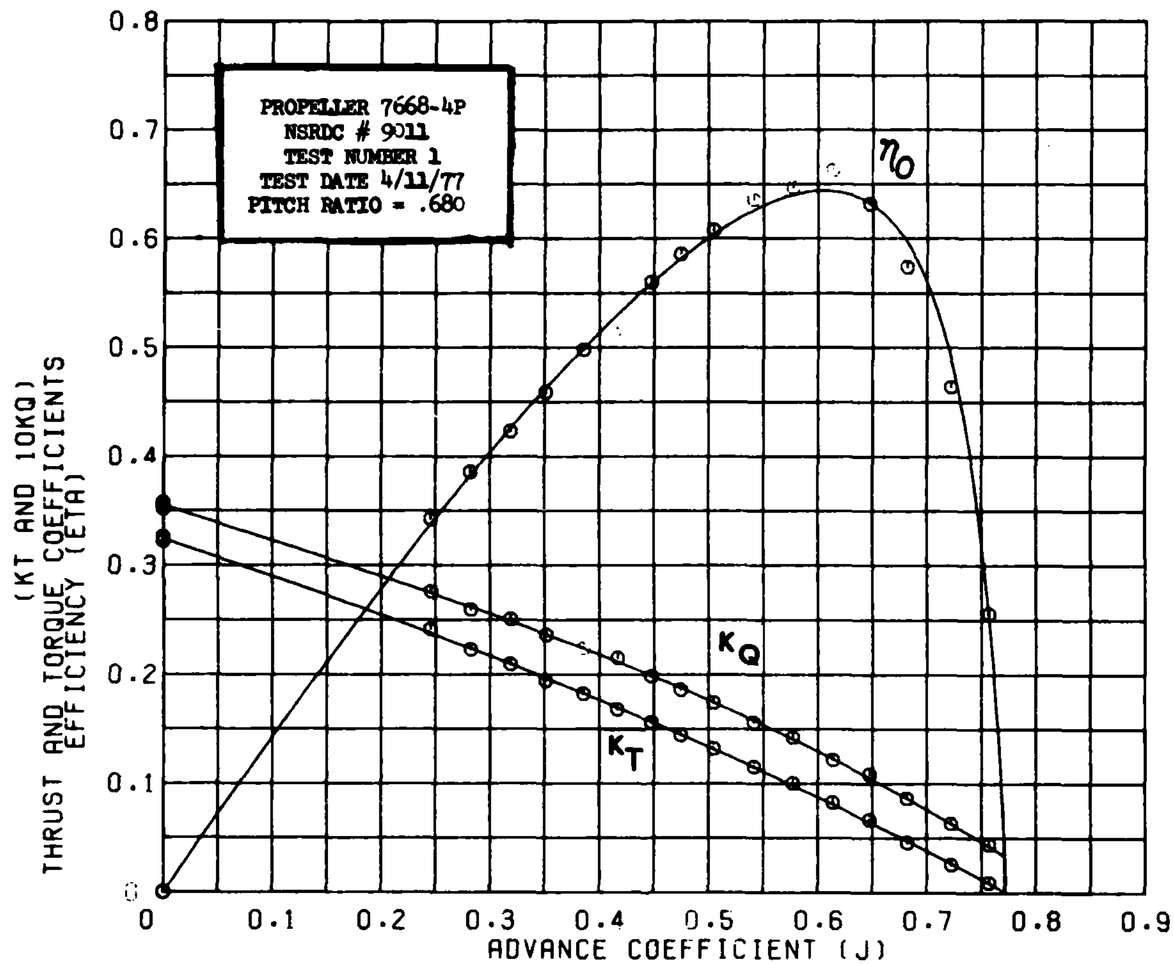


Figure 12 - Open Water Curves for Propeller 9011

CORRELATION OF PREDICTIONS FROM EXPERIMENTS WITH MODEL 9006
WITH POWERING DATA FROM SHIP TRIALS

LENGTH (LBP)	300.0 m	PROPELLER DIAMETER	9.208 m
BEAM	50.0 m	PROPELLER PITCH	6.265 m
DRAFT	20.70 m fwd		
	20.72 m aft	ITTC FRICTION FORMULATION	
DISPLACEMENT	267,763 m tons	TRIAL DATA CORRECTED FOR STILL AIR DRAG	
WETTED SURFACE	24,190 m^2	CORRELATION ALLOWANCE (C_A) = -0.00015	

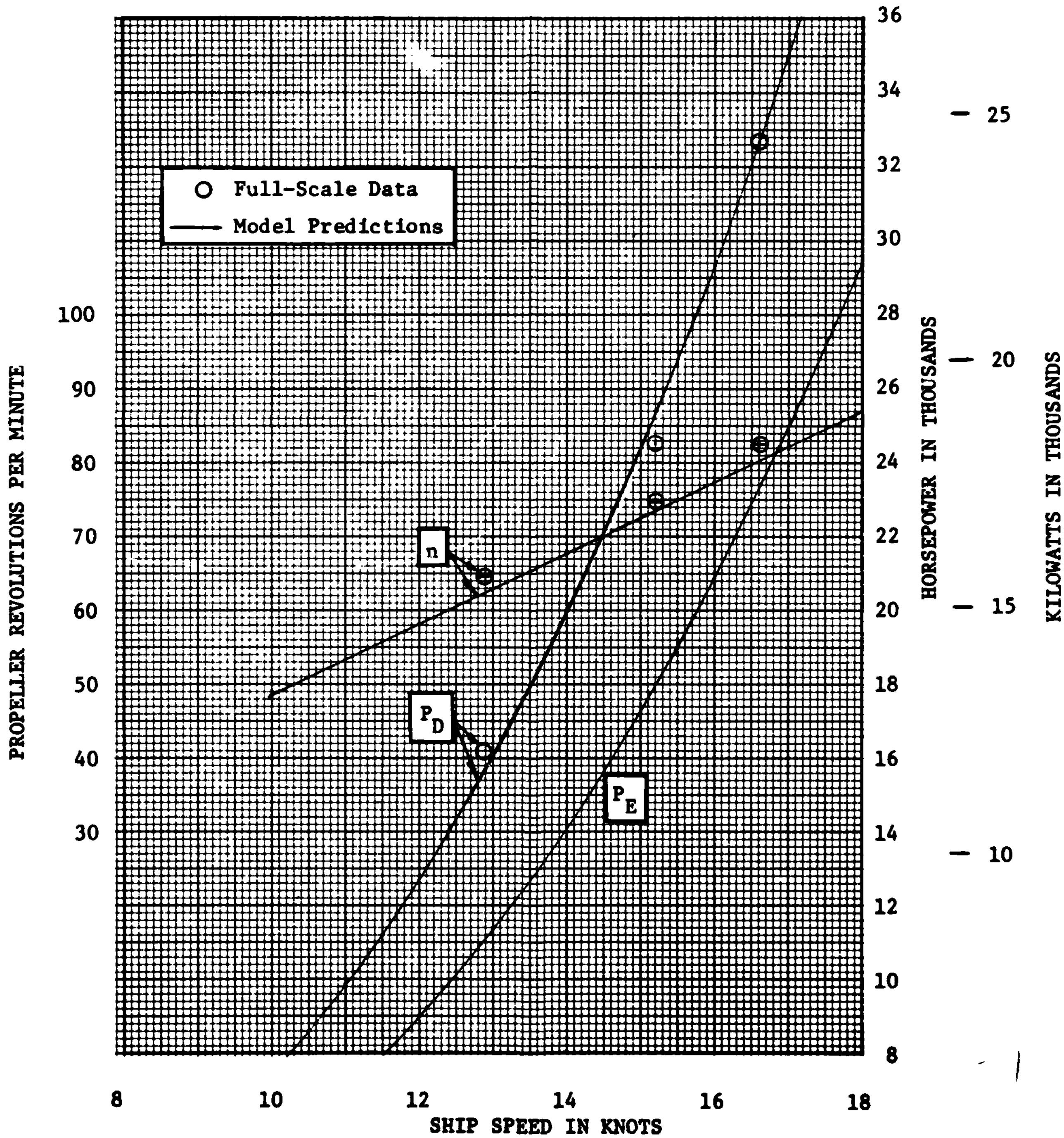


FIGURE 13

CORRELATION OF PREDICTIONS FROM EXPERIMENTS WITH MODEL 9007
WITH POWERING DATA FROM SHIP TRIALS

LENGTH (LBP)	347.8 m	PROPELLER DIAMETER	9.396 m
BEAM	51.8 m	PROPELLER PITCH	6.368 m
DRAFT	18.74 m fwd		
	19.39 m aft	ITTC FRICTION FORMULATION	
DISPLACEMENT	276,850 m tons	TRIAL DATA CORRECTED FOR STILL AIR DRAG	
WETTED SURFACE	26,216 m^2	CORRELATION ALLOWANCE (C_A) = -0.0004	

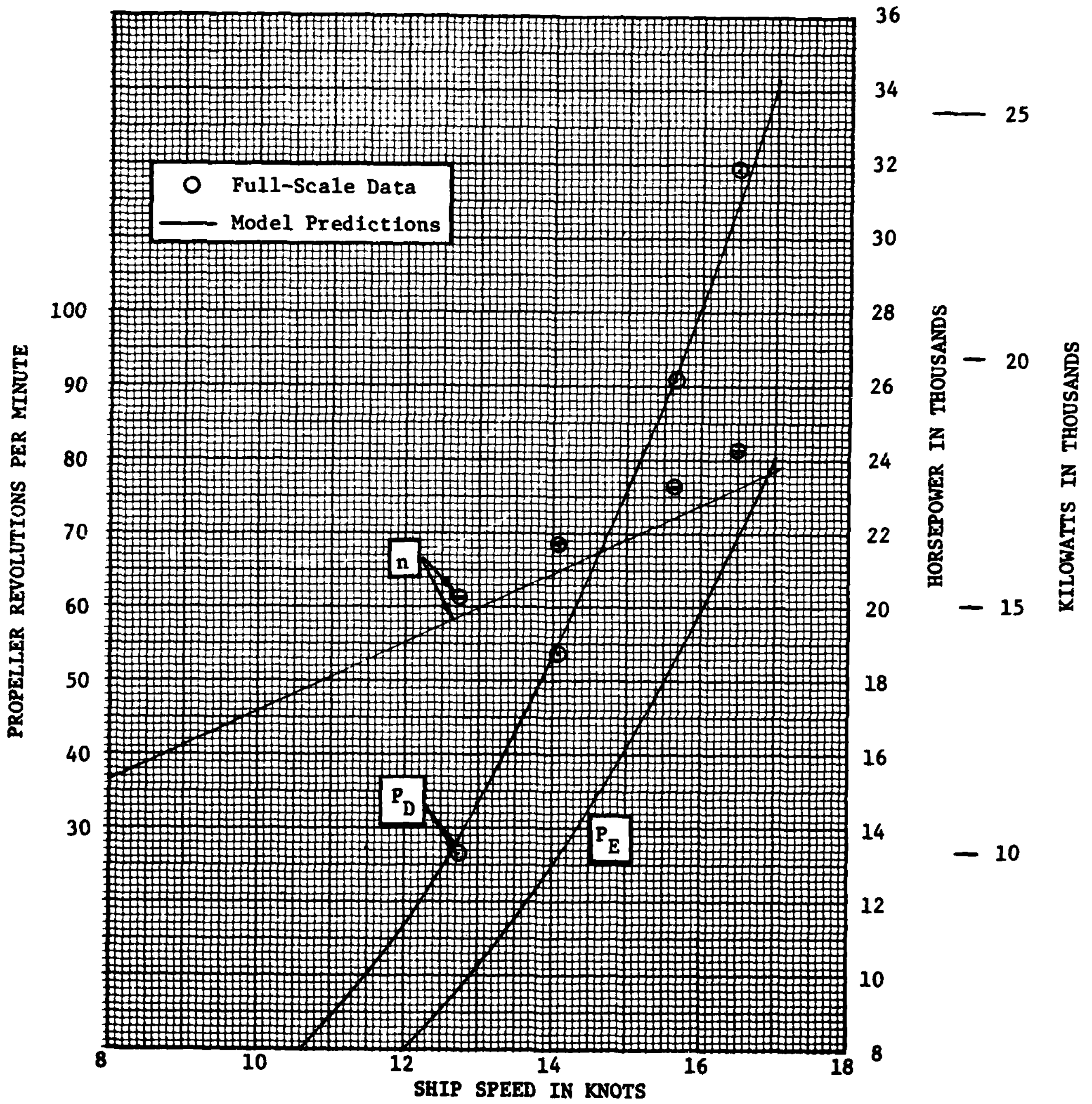


FIGURE 14

CORRELATION OF PREDICTIONS FROM EXPERIMENTS WITH MODEL 9008
WITH POWERING DATA FROM SHIP TRIALS

LENGTH (LBP)	313.0 m	PROPELLER DIAMETER	7.741 m
BEAM	51.0 m	PROPELLER PITCH	5.332 m
DRAFT	19.87 m fwd	ITTC FRICTION FORMULATION	
	19.87 m aft	TRIAL DATA CORRECTED FOR STILL AIR DRAG	
DISPLACEMENT	266,854 m tons	CORRELATION ALLOWANCE (C_A) = -0.00025	
WETTED SURFACE	25,149 m^2		

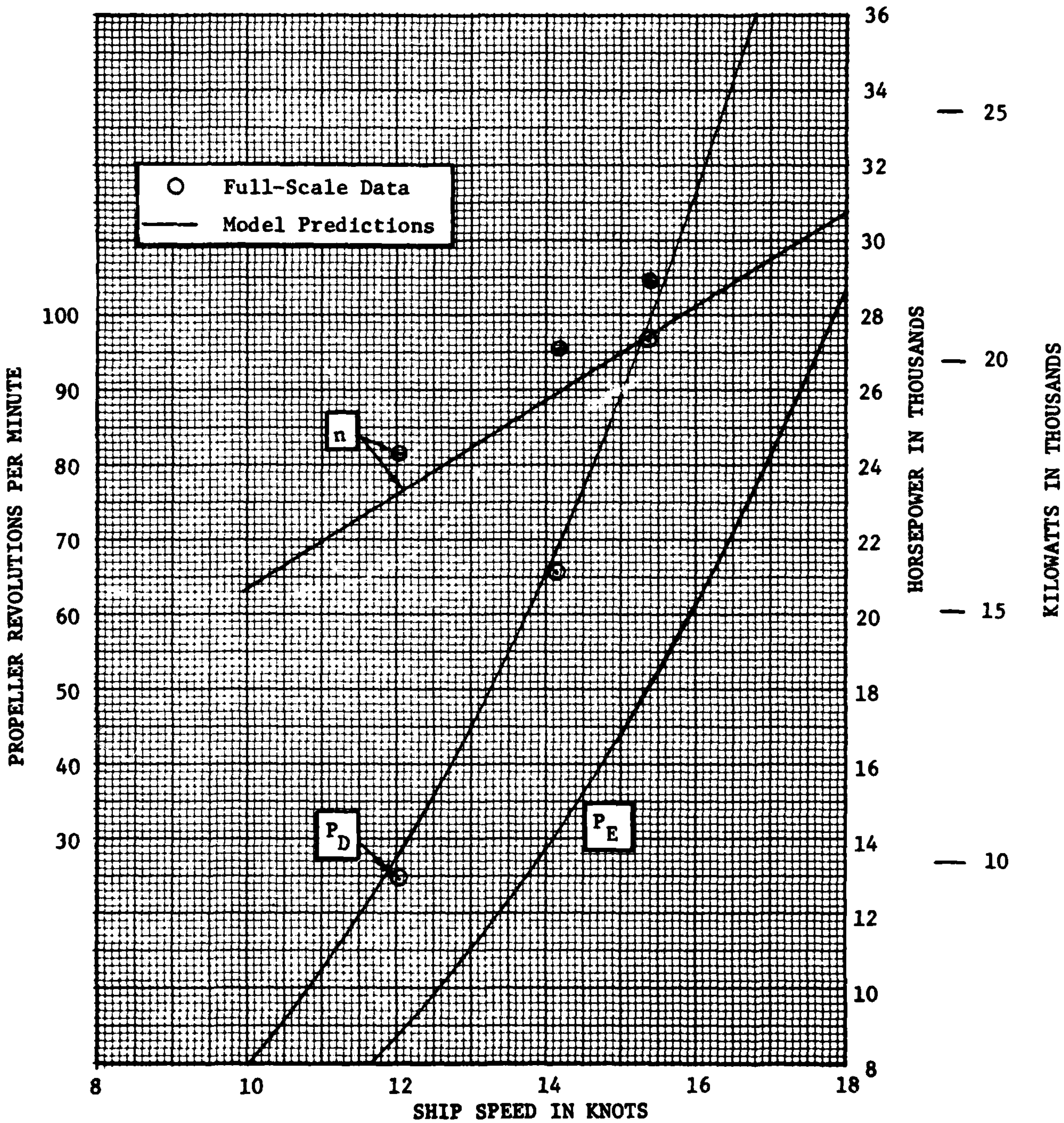


FIGURE 15

CORRELATION OF PREDICTIONS FROM EXPERIMENTS WITH MODEL 9009
WITH POWERING DATA FROM SHIP TRIALS

LENGTH (LBP)	300.0 m	PROPELLER DIAMETER	9.208 m
BEAM	50.0 m	PROPELLER PITCH	6.265 m
DRAFT	20.70 m fwd		
	20.72 m aft	ITTC FRICTION FORMULATION	
DISPLACEMENT	267,763 m tons	TRIAL DATA CORRECTED FOR STILL AIR DRAG	
WETTED SURFACE	24,190 m^2	CORRELATION ALLOWANCE (C_A) = -0.00015	

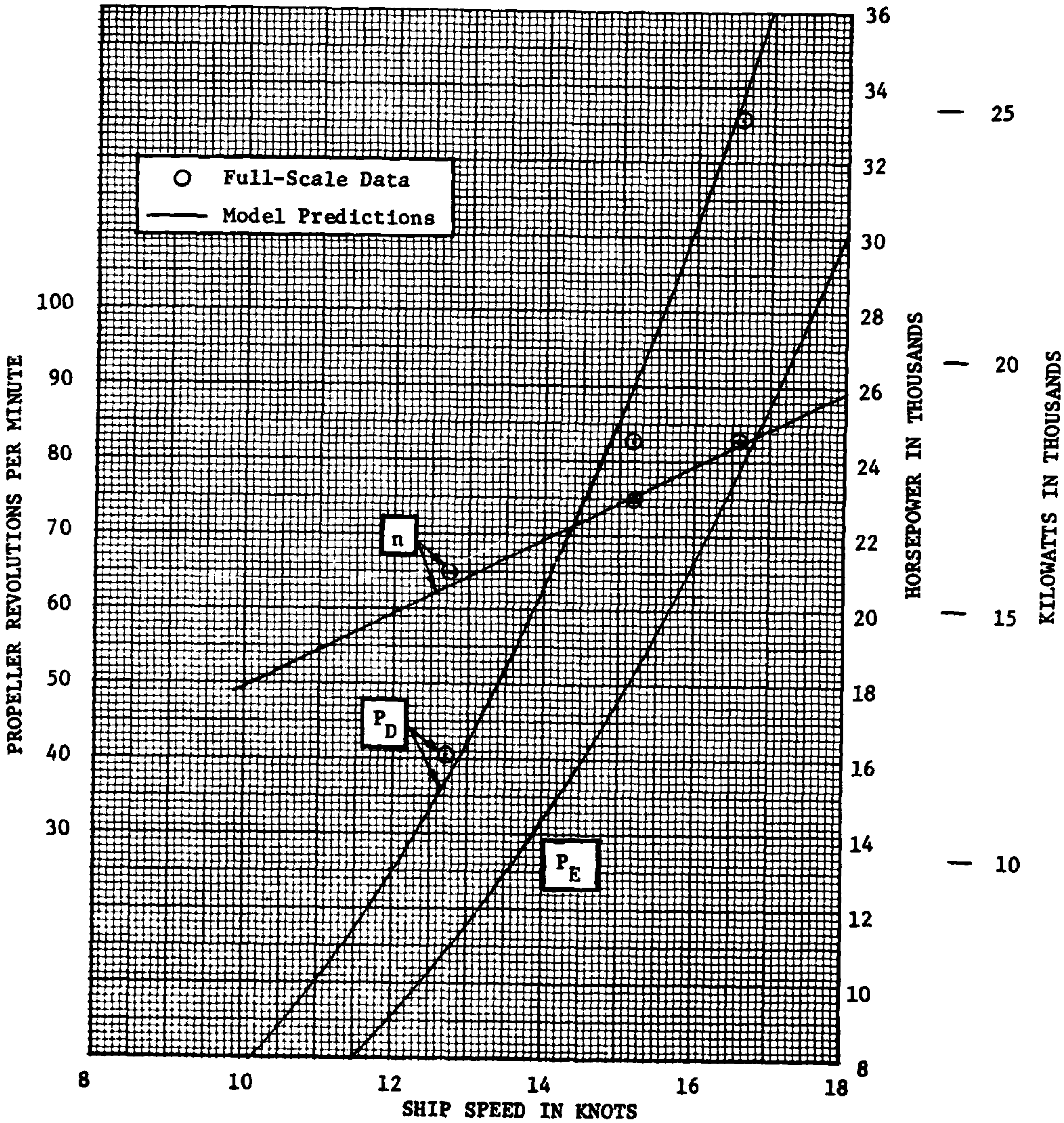


FIGURE 16

TABLE 1

FULL-SCALE INFORMATION FOR THE SHIP REPRESENTED BY MODELS 9006 AND 9009

Length Overall in meters	317.0
Length Between Perpendiculars in meters	300.0
Beam in meters	50.0
Draft Forward in meters	20.70
Draft Aft in meters	20.72
Displacement in metric tons	267,763
Wetted Surface in square meters	24,190
Propeller Diameter in meters	9.208
Propeller Pitch in meters	6.265
Number of Blades	5

TRIAL DATA

Ship Speed		Ship Speed Corrected for Still Air Drag		Metric Horsepower	British Horse-power		Propeller Speed
knots	m/s	knots	m/s			kilowatts	RPM
12.70	6.53	12.87	6.62	16,400	16,180	12,060	64.9
15.00	7.72	15.20	7.82	24,875	24,530	18,300	74.9
16.40	8.44	16.60	8.54	33,100	32,650	24,340	82.5

TABLE 2

FULL-SCALE INFORMATION FOR THE SHIP REPRESENTED BY MODEL 9007

Length Overall in meters	347.8
Length Between Perpendiculars in meters	329.2
Beam in meters	51.8
Draft Forward in meters	18.74
Draft Aft in meters	19.39
Displacement in metric tons	276,850
Wetted Surface in square meters	26,216.
Propeller Diameter in meters	9.392
Propeller Pitch in meters	6.668
Number of Blades	4

TRIAL DATA

Ship Speed		Ship Speed Corrected for Still-Air Drag		Metric Horsepower	British Horsepower		Propeller Speed
knots	m/s	knots	m/s			kilowatts	RPM
12.55	6.46	12.72	6.54	13,400	13,220	9,858	61.0
13.90	7.15	14.09	7.25	19,050	18,790	14,012	68.2
15.42	7.93	15.63	8.04	26,550	26,190	19,530	76.2
16.28	8.38	16.49	8.48	32,300	31,860	23,758	81.2

TABLE 3

FULL-SCALE INFORMATION FOR THE SHIP REPRESENTED BY MODEL 9008

Length Overall in meters	333.9
Length Between Perpendiculars in meters	313.0
Beam in meters	51.0
Draft Forward in meters	19.87
Draft Aft in meters	19.87
Displacement in metric tons	266,854.
Wetted Surface in square meters	25,149.
Propeller Diameter in meters	7.741
Propeller Pitch in meters	5.332
Number of Blades in meters	6

TRIAL DATA

Ship Speed		Ship Speed Corrected for Still Air Drag		Metric Horsepower	British Horsepower		Propeller Speed
knots	m/s	knots	m/s			kilowatts	RPM
11.85	6.10	12.03	6.19	13,155	12,970	9,672	81.6
13.96	7.18	14.17	7.29	21,340	21,050	15,697	95.4
15.17	7.80	15.41	7.93	27,745	27,365	20,406	104.2

TABLE 4

PRINCIPAL DIMENSIONS OF MODELS AND PROPELLERS

DTNSRDC Model Number	9006	9007	9008	9009
Scale Ratio (λ)	42.793	46.958	39.496	32.808
Length Overall	24.30 ft (7.407 m)	24.30 ft (7.407 m)	27.74 ft (8.455 m)	31.70 ft (9.662 m)
Length Between Perpendiculars	23.00 ft (7.010 m)	23.00 ft (7.010 m)	26.00 ft (7.925 m)	30.00 ft (9.144 m)
Beam	3.83 ft (1.167 m)	3.62 ft (1.103 m)	4.24 ft (1.292 m)	5.00 ft (1.524 m)
Draft Forward	1.587 ft (0.484 m)	1.308 ft (0.399 m)	1.65 ft (0.503 m)	2.070 ft (0.631 m)
Draft Aft	1.589 ft (0.484 m)	1.354 ft (0.413 m)	1.65 ft (0.503 m)	2.072 ft (0.632 m)
Displacement	7326 lbs (32.59 kN)	5732 lb (25.50 kN)	9286 lb (41.30 kN)	16256 lb (723.06 kN)
Wetted Surface	142.19 ft^2 (13.210 m^2)	127.97 ft^2 (11.889 m^2)	173.54 ft^2 (16.122 m^2)	241.88 ft^2 (22.471 m^2)
DTNSRDC Propeller Number	9008	9009	9010	9011
Propeller Diameter	0.7059 ft (0.215 m)	0.6573 ft (0.200 m)	0.6438 ft (0.196 m)	0.9208 ft (0.281 m)
Propeller Pitch at 0.7 Radius	0.4803 ft (0.146 m)	0.4667 ft (0.142 m)	0.4428 ft (0.135 m)	0.6264 ft (0.191 m)
Number of Blades	5	4	6	5
Tow Tank Water Temperature	74°F (23.3°F)	74.°F (23.3°C)	74°F (23.3°C)	75°F (23.9°C)

TABLE 5

MODEL 9006 - PREDICTED POWERING PERFORMANCE
FOR A DISPLACEMENT OF 263,547 TONS (267,764 t)
AND A CORRELATION ALLOWANCE OF -0.00015

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER (PE) (HORSE-POWER)	EFFECTIVE POWER (PE) (KILO-WATTS)	DELIVERED POWER (PD) (HORSE-POWER)	DELIVERED POWER (PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE
10.0	5.14	5280.	3940.	7440.	5550.	46.4
11.0	5.66	6970.	5200.	9830.	7330.	53.2
12.0	6.17	9000.	6710.	12670.	9450.	58.1
13.0	6.69	11370.	8480.	16020.	11940.	62.9
14.0	7.20	14120.	10530.	19860.	14810.	67.8
15.0	7.72	17280.	12890.	24310.	18130.	72.5
16.0	8.23	20880.	15570.	29360.	21900.	77.4
17.0	8.75	24930.	18590.	35060.	26150.	82.3
18.0	9.26	29470.	21980.	41450.	30910.	87.0

SHIP SPEED (KNOTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	.710	.445	1.615	.985	.760	.470	.455	.325
11.0	.710	.450	1.600	.985	.760	.475	.460	.330
12.0	.710	.455	1.585	.990	.760	.480	.470	.335
13.0	.710	.460	1.565	.990	.760	.485	.475	.335
14.0	.710	.460	1.550	.995	.760	.490	.485	.340
15.0	.710	.460	1.550	.990	.760	.490	.480	.340
16.0	.710	.465	1.535	.995	.760	.495	.490	.345
17.0	.710	.470	1.520	.995	.760	.500	.495	.345
18.0	.710	.470	1.520	.995	.760	.500	.495	.345

TABLE 6

MODEL 9007 - PREDICTED POWERING PERFORMANCE FOR A DISPLACEMENT OF 272,490 TONS (276,850 t) AND A CORRELATION ALLOWANCE OF -0.0004

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER (PE) (HORSE-POWER)	EFFECTIVE POWER (PE) (KILO-WATTS)	DELIVERED POWER (PD) (HORSE-POWER)	DELIVERED POWER (PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE
8.0	4.12	2450.	1820.	3490.	2610.	36.7
9.0	4.63	3440.	2570.	4920.	3670.	41.2
10.0	5.14	4630.	3450.	6680.	4980.	45.8
11.0	5.66	6170.	4600.	8820.	6580.	50.3
12.0	6.17	7950.	5930.	11340.	8460.	54.8
13.0	6.69	10390.	7660.	14640.	10920.	59.6
14.0	7.20	13120.	9790.	18670.	13920.	64.4
15.0	7.72	16210.	12090.	23030.	17170.	69.1
16.0	8.23	19870.	14820.	28190.	21020.	73.8
17.0	8.75	24080.	17960.	34150.	25470.	78.5

SHIP SPEED (KNOTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
8.0	.700	.495	1.490	.955	.760	.510	.455	.365
9.0	.700	.500	1.475	.955	.760	.515	.460	.370
10.0	.700	.505	1.450	.955	.760	.525	.470	.375
11.0	.700	.510	1.435	.955	.760	.530	.475	.380
12.0	.700	.515	1.420	.955	.760	.535	.485	.385
13.0	.700	.505	1.450	.960	.760	.525	.475	.375
14.0	.705	.495	1.475	.960	.760	.515	.470	.370
15.0	.705	.495	1.475	.965	.760	.515	.470	.365
16.0	.705	.490	1.490	.965	.760	.510	.465	.365
17.0	.705	.485	1.505	.965	.760	.505	.465	.360

TABLE 7

MODEL 9008 - PREDICTED POWERING PERFORMANCE FOR A DISPLACEMENT OF 262,652 TONS (266,854 t) AND A CORRELATION ALLOWANCE OF -0.00025

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER (PE) (HORSE-POWER)	EFFECTIVE POWER (PE) (KILO-WATTS)	DELIVERED POWER (PD) (HORSE-POWER)	DELIVERED POWER (PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE
10.0	5.14	47[illegible]0.	3570.	7370.	5490.	61.5
11.0	5.66	63[illegible]0.	[illegible]	9730.	72[illegible]0.	67.8
12.0	[illegible].17	81[illegible]0.	[illegible]	12[illegible]0.	9350.	73.9
13.0	6.69	10290.	7670.	15820.	11800.	80.0
14.0	7.20	12770.	[illegible]20.	19840.	14650.	86.1
15.0	7.72	15610.	11640.	24020.	17910.	92.3
16.0	8.23	18860.	14050.	28990.	21620.	98.5
17.0	8.75	22470.	16770.	34600.	25800.	104.7
18.0	9.26	26570.	19810.	40980.	30460.	110.6

SHIP SPEED (KNOTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFIT	1-WFTQ	ADVANCE COEF. ADVC
10.0	.650	.425	1.610	.950	.780	.485	.425	.315
11.0	.650	.430	1.575	.955	.780	.495	.440	.320
12.0	.650	.435	1.560	.955	.780	.500	.445	.325
13.0	.650	.440	1.545	.955	.780	.505	.455	.325
14.0	.650	.445	1.530	.960	.780	.510	.460	.330
15.0	.650	.445	1.515	.960	.780	.515	.470	.335
16.0	.650	.450	1.500	.960	.780	.520	.475	.335
17.0	.650	.455	1.485	.965	.780	.525	.485	.340
18.0	.650	.455	1.485	.960	.780	.525	.480	.340

TABLE 8

MODEL 9009 - PREDICTED POWERING PERFORMANCE
FOR A DISPLACEMENT OF 263,547 TONS (267,764 t)
AND A CORRELATION ALLOWANCE OF -0.00015

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE
10.0	5.14	5370.	4016.	7660.	5710.	49.6
11.0	5.66	7100.	5300.	10120.	7540.	54.5
12.0	6.17	9160.	6830.	13050.	9730.	59.5
13.0	6.69	11560.	8630.	16490.	12300.	64.3
14.0	7.20	14380.	10730.	20490.	15280.	69.3
15.0	7.72	17600.	13130.	25070.	18700.	74.3
16.0	8.23	21250.	15860.	30290.	22590.	79.4
17.0	8.75	25330.	18890.	36170.	26980.	84.2
18.0	9.26	30020.	22390.	42770.	31890.	89.2

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	.700	.470	1.495	.995	.770	.515	.510	.350
11.0	.700	.475	1.480	.995	.770	.520	.515	.350
12.0	.700	.480	1.465	1.000	.770	.525	.525	.355
13.0	.700	.480	1.465	.995	.770	.525	.520	.355
14.0	.700	.485	1.455	1.000	.770	.530	.530	.360
15.0	.700	.490	1.440	1.000	.770	.535	.535	.360
16.0	.700	.490	1.425	1.000	.770	.540	.540	.365
17.0	.700	.490	1.425	1.000	.770	.540	.540	.365
18.0	.700	.495	1.415	1.005	.770	.545	.550	.370

TABLE 9

COMPARISON OF PREDICTIONS FROM MODEL EXPERIMENTS WITH FULL-SCALE POWER AND RPM MEASUREMENTS

Ship Speed Corrected for Still Air Drag (knots)	Delivered Power (kw)	Propeller RPM	Delivered Power (kw)	Propeller RPM
Model 9006	Model Predictions ($C_A = -0.00015$)		Full-Scale Result	
12.87	11670	62.5	12,060	64.9
15.20	18866	73.5	18,300	74.9
16.60	24309	80.0	24,340	82.5
Model 9007	Model Predictions ($C_A = -0.0004$)		Full-Scale Result	
12.72	10216	58.6	9,858	61.0
14.09	14131	64.9	14,012	68.2
15.63	19537	72.1	19,530	76.2
16.49	23079	76.1	23,758	81.2
Model 9008	Model Predictions ($C_A = -0.00025$)		Full-Scale Result	
12.03	10104	76.2	9,672	81.6
14.17	16256	89.6	15,697	95.4
15.41	20581	97.5	20,406	104.2
Model 9009	Model Predictions ($C_A = -0.00015$)		Full-Scale Result	
12.87	11894	63.8	12,060	64.9
15.20	19462	75.2	18,300	74.9
16.60	25167	81.8	24,340	82.5

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